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Application of an Ecological Model for the Cibolo Creek Watershed

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BACKGROUND: The U.S. Army Engineer District, Fort Worth (CESWF) is involved in demonstrating the utility of an ecological model in the performance and interpretation of a comprehensive General Investigations (GI) study of the Cibolo Creek watershed upstream of Interstate 10 near San Antonio, Texas. Partners to the District in this project are the Natural Resources Conservation Service (NRCS), U.S. Geological Survey (USGS), and U.S. Fish and Wildlife Service (USFW). Project sponsors are the Guadalupe-Blanco River Authority (GBRA), San Antonio River Authority (SARA), and San Antonio Water System (SAWS). CESWF requested assistance from the U.S. Army Engineer Research and Development Center (ERDC) in conducting this study. The first phase of the study was to establish existing conditions of the hydrologic, engineering, economic, and environmental aspects of the study area, and to demonstrate watershed modeling tools. The second phase will evaluate a recharge/dry detention structure to identify the relative magnitude of the structure's flood damage reduction and aquifer recharge benefits. The third phase will formulate and screen alternatives to meet national and local plans regarding detention structures, restoration of aquatic habitats and hydrology, reforested riparian and wetland buffer zones, creation of emergent wetlands, brush management techniques, watershed policies dealing with urban/suburban growth, and nonstructural flood damage reduction. During the first phase, researchers at ERDC set up and demonstrated the ecological model. Implementation of the second phase is dependent on evaluation of the first phase by the sponsors.

OBJECTIVES: The objective of phase 1 was to set up and parameterize the Ecological Dynamics Simulation (EDYS) model for a 165-square-mile portion of the Cibolo Creek watershed, north and west from U.S. Highway 281. The second objective was to demonstrate the utility of the EDYS model in simulating the likely outcomes of watershed management alternatives for the Cibolo watershed. The third objective was to provide input data from EDYS simulations to USGS modelers to improve the calibration of the watershed hydrology model (HSPF) and thereby improve estimates of evaporation and transpiration from the vegetation and landscape.

PROJECT DESCRIPTION AND BENEFIT: The focus of the project was to provide the District, State Water Authorities, and city and county officials with one of the simulation tools necessary to allow them to project, over a 50-year planning horizon, the outcomes of:

- No Federal initiative in land and water use (i.e., no brush control or urban/suburban growth control)
- A federal initiative that may include brush control, urban/suburban/ rural best management practices, prescribed fire, and changes in precipitation patterns.

Specifically, will the federal initiatives provide recharge potential to the aquifer, environmental restoration, and/or flood damage protection?

EDYS has been applied in a wide variety of land/water management scenarios, including: military training, recreational activities, grazing, natural and prescribed burns, fire suppression, road/trail building and closure, invasive plants inventory and eradication, drought assessment, water quality/quantity, reclamation, restoration, and revegetation, land cover design, and slope stability. EDYS is designed to mechanistically simulate complex ecological dynamics across spatial scales ranging from plots (square meters) to landscape and watershed (square kilometers) levels. Modules include climatic simulators, hydrology, soil profile, nutrient and contaminant cycles, plant community dynamics, herbivory, animal dynamics, management activities, and natural/anthropogenic disturbances (Childress et al. 1999).

Parameterization of the EDYS model for the Cibolo Creek watershed (Figure 1), was primarily funded by the Fort Worth District. This included working with District personnel and their partners from the NRCS to develop a vegetation map for the watershed and to collect specific biological information from representative vegetation types that occur in the watershed. Dennis Akins of the Fort Worth District developed the initial vegetation map using a supervised classification of satellite imagery and ground truth information collected by NRCS personnel. Existing EDYS databases developed for an application of the model for Camp Bullis, Texas in the Cibolo watershed and aerial photography of the watershed were also used to refine the vegetation map.

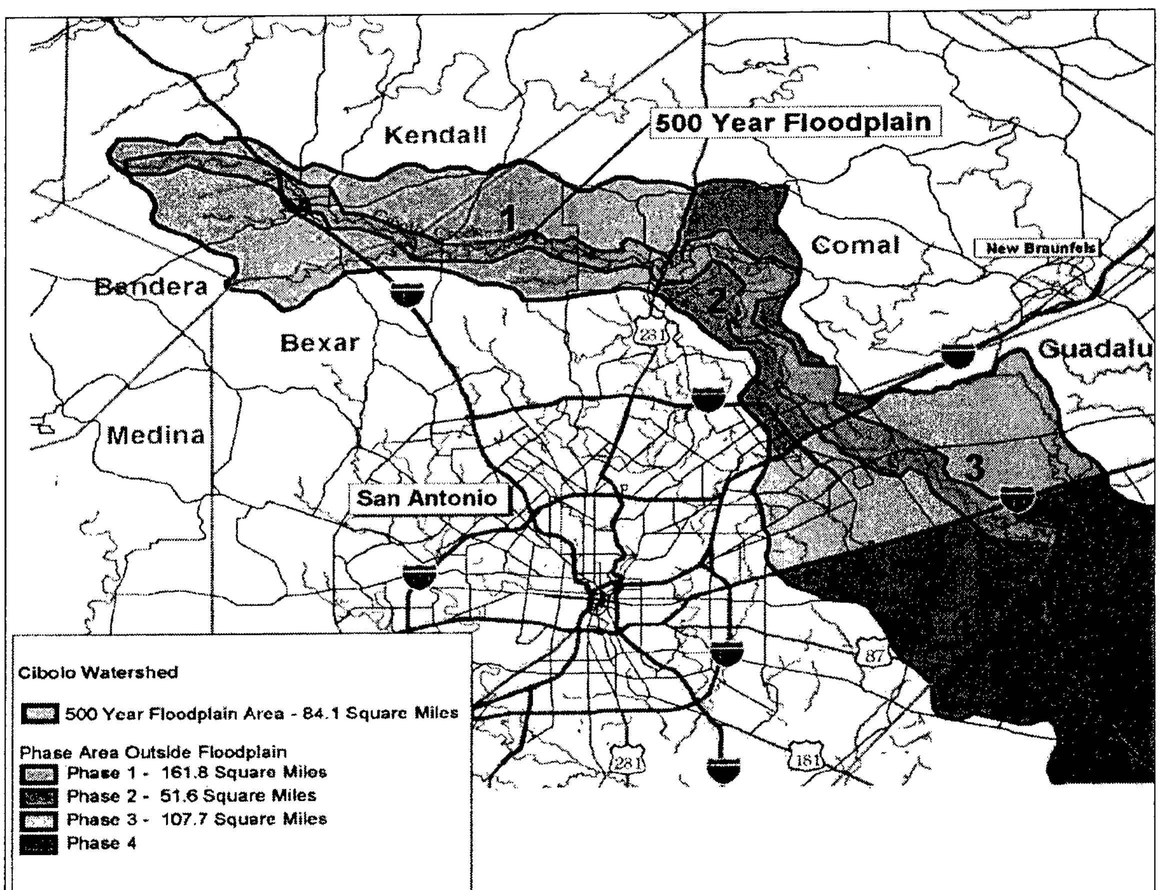

Figure 1. Cibolo Creek watershed near San Antonio, Texas

The parameterization process resulted in 24 vegetation and land-use types. The watershed was partitioned into 30- by 30-m grid cells for spatial representation and each grid cell was assigned a vegetation type based on the vegetation map.

EDYS DEMONSTRATION SETUP: Demonstration of the EDYS model for the Cibolo Creek project was primarily funded by the Water Operations Technical Support (WOTS) Program of the Environmental Laboratory at ERDC, Vicksburg. The demonstration process included working directly with the sponsors (SARA, GBRA, SAWS) and Fort Worth District personnel to develop the watershed management options to be included in the demonstration (Table 1). These management options are the current or projected, primary land uses in the watershed that may have a significant effect on the ecological condition of the watershed or the water budget, including quantity and quality of the surface and groundwater.

Table 1
Management Options Developed by Project Sponsors for the EDYS Demonstration

Management Option	Anticipated Result (Land use or Management Action)
Urban growth into the watershed	Buildings, roads, driveways, yards
Brush management	Dozing, mechanical cut, hand cut, fire
Livestock grazing	Type, stocking rate, season of use
Cultivation	Small grains, add or remove areas
Improved pasture	Current pastures, add or remove pastures
Fertilization	Nitrogen, variable rates of application, any area
Herbicide use	2,4-D, picloram, dicamba
Reseeding	Any included vegetation type, variable rates and area
Hunting	Species, seasons, harvest rates
Irrigation	Yards, pastures, crop fields

Therefore, the sponsors required that the following end-point variables be evaluated in the demonstration of the simulations:

- Water quantity (including recharge to the Edwards Aquifer and run-off to a receiving water).
- Surface and groundwater quality (including sediment and nitrogen loadings).
- Ecological change or restoration potential in the watershed (including changes in major vegetation types).

Based on these management options and end-point variables, four simulation variables were chosen for evaluation. The simulation variables are listed in Table 2. The simulation period to be evaluated was 50 years based on precipitation records from 1951 – 2000. Urban growth was based on actual population growth rates for Bexar, Comal, and Kendal Counties over the period 1951 – 2000. Annual compound rates for the three-county area over that period was about 3 percent on average.

Table 2
Simulation Variables Developed for the EDYS Demonstration

Variable	Options
Precipitation	Average period, wet period, dry period
Brush control	None, clear juniper in woodlands or in grassland vegetation types
Urban growth rate	No change, increased rate, decreased rate
Urban growth location	Hilltops, bottom lands, randomly located

All combinations of these four variables would require 81 separate simulations; therefore, a reduced set of simulation scenarios was developed to represent a range of reasonable possibilities that could be evaluated against baseline conditions (Table 3). Baseline conditions were defined as an average precipitation period (average 50-year ppt), no brush control, and no urban growth.

EDYS SIMULATION RESULTS: Under baseline conditions the major vegetation change that is projected to occur over the 50-year simulation period is a significant increase in juniper and a decrease in live oak across all woodland vegetation types in the watershed (Table 4). During pre-settlement times the mosaic of woodlands, oak savanna, and grasslands was maintained by fire; however, under current management constraints fire is not often a reasonable choice as a management tool.

Table 3
Simulation Scenarios to be Evaluated Against Baseline Conditions

Simulation Scenario	Options
Baseline	Average precipitation, no brush control, no urban growth
Brush control options	5% annual juniper removal in woodlands, no growth, average 50-yr ppt[1]
	5% annual juniper removal in woodlands, no growth, dry 50-yr ppt
	5% annual juniper removal in woodlands, no growth, wet 50-yr ppt
	20% annual juniper removal in grasslands, no growth, average 50-yr ppt
Urban growth rate	3% annual increase; with dry, average, and wet ppt periods
	4% annual increase; with dry, average, and wet ppt periods
Urban growth location	3% annual increase on hilltops; with average and wet ppt periods
	3% annual increase in bottoms; with average and wet ppt periods

[1] ppt designates the 50-year precipitation period being either dry, average, or wet.

In cases where fire cannot be used, juniper removal is accomplished by mechanical means, herbicide application, or hand-cutting.

Without juniper control (baseline), juniper will increase significantly over periods of 25 and 50 years and live oak will decrease. Implementing juniper control of 90-percent removal on 5 percent of the woodland areas each year maintains juniper to about 1000 grams per meter square at 25 years and about 1300 grams per meter square at 50 years for dry, average, and wet periods (Table 5).

Over the 50-year simulation period the effect of juniper control on selected woodlands and grasslands can result in significant changes in average annual recharge and runoff over the entire watershed. Results of the simulation show that recharge increases by 20 to 80 thousand acre-feet over base-line depending on the control option in combination with average, dry, or wet precipitation periods. Runoff, as a percent of baseline, decreases with control of juniper on the grasslands or the woodlands under average, dry, or wet periods (Table 6).

Table 4
50-Year Change in Juniper and Live Oak Under Baseline Conditions as Total Aboveground Biomass (g/m2) for all Woodland Vegetation Types (ppt = annual mean precipitation over a 5-year period)

Year	ppt	Juniper g/m^2	Live Oak g/m^2
00[1]	0	4,221	4,306
05	21	4,001	3,255
10	35	4,416	3,200
15	28	4,837	3,154
20	32	5,282	2,105
25	41	5,714	3,051
30	36	6,002	2,995
35	34	6,243	2,946
40	34	6,531	2,905
45	42	6,487	2,873
50	38	6,545	2,835

[1] Year 00 designates initial conditions of the variables at the start of the model simulation.

The effect of the location of urbanization on the landscape (urbanization on the hilltops versus on the bottomlands) also has a significant effect on annual water yields. Urbanization on the hilltops results in greater recharge via karst features than urbanization on bottomlands, by as much as 33 percent during wet periods to 37 percent during average periods. Runoff increases by 133 percent during wet periods to 141 percent during average periods if urbanization takes place on the hilltops compared to urbanization mainly on the bottomlands (Table 7).

Table 5
Woodland Vegetation Response, to Juniper Control as Total Aboveground Biomass (g/m2) at 90% Removal of Juniper on 5% of Woodlands per Year as Compared to Baseline Under Dry, Average, and Wet Periods (ppt)

Vegetation Type	Simulation Year								
	00[1] Initial Conditions	25 Baseline	25 Dry, ppt	25 Average ppt	25 Wet, ppt	50 Baseline	50 Dry, ppt	50 Average ppt	50 Wet, ppt
Juniper	4095	5714	941	1005	1046	6545	1250	1302	1337
Live oak	3406	3051	3095	3110	3120	2835	2995	3016	3033

[1] Year 00 designates initial conditions of the variables at the start of the model simulation.

Table 6
Effects of Juniper Control Options on Average Annual Recharge (in 1,000 acre-feet), and Runoff (as a percent of baseline) from the Entire Watershed with Juniper Control on Selected Grasslands (G) 20% Annually or Woodlands (W) 5% Annually

Recharge (1,000 acre-feet)					Runoff (as percent of baseline)				
Baseline Average ppt	20% G Average ppt	5% W Average ppt	5% W Dry, ppt	5% W Wet, ppt	Baseline Average ppt	20% G Average ppt	5% W Average ppt	5% W Dry, ppt	5% W Wet, ppt
162	182	224	197	243	320	52%	55%	44%	64%

Table 7
Effect of Location of Urbanization on Annual Water Yields for the Entire Watershed for Profile Recharge, Karst Recharge, and Runoff[1]

Location	Profile Recharge		Karst Recharge		Runoff	
	Average, ppt	Wet, ppt	Average, ppt	Wet, ppt	Average, ppt	Wet, ppt
Bottom vs. Hilltop	0%	0%	37%	33%	141%	133%

[1] Values are expressed as the percent Increase from development in bottoms versus hilltops.

Changes in the annual population growth rate and urbanization into the watershed will have an impact on runoff and sediment loads. Increases in the annual growth rates from 0 to 3 percent, and from 3 to 4 percent increase runoff by 78 and 184 percent, and sediment load by 280 and 516 percent averaged over a period of 42 years (Table 8).

Table 8
Effect of Increasing Annual Growth Rates (0 to 3% and 3 to 4%) and Subsequent Urbanization into the Watershed on Runoff and Sediment Loads Based on 42-Year Averages

Annual Growth Rate	Runoff (in percent)	Sediments (in percent)
0%	N/A	N/A
3%	78%	280%
4%	184%	516%

SUMMARY AND CONCLUSIONS: Evaluation of different management options using the EDYS model indicates that without an aggressive brush control or management plan in the Cibolo Creek watershed and without careful urban planning as the population in the area grows, there will be significant undesirable changes in recharge and runoff for the watershed over the next 50 years, including:

- A 3-percent annual growth rate over the next 42 years will result in an increase in runoff of 78 percent leaving the watershed.
- No juniper control over the next 50 years will result in a 50-percent increase in juniper and a 20-percent reduction in live oak and an annual loss of 17,000 acre-feet of water yield as recharge from the watershed.

Under baseline conditions of no brush control, no population growth and urbanization, and average precipitation, the average annual potential recharge would be 183,000 acre-feet or 39 percent of rainfall received. Over the 50-year baseline period, juniper would increase by 55 percent and live oak would decrease by 17 percent. Compared to baseline, implementing a juniper management scheme of removing 90 percent of the juniper on 5 percent of the woodlands per year would increase the annual recharge to 224,000 acre-feet.

Compared to no growth, a 3-percent annual growth rate evenly distributed across the watershed will decrease annual recharge by 16,000 acre-feet or about 9 percent. Runoff will increase by 78 percent and sediment load will increase by 280 percent. A 4-percent annual growth rate will decrease annual recharge by 26,000 acre-feet (14 percent), increase runoff by 184 percent, and increase sediment load by 516 percent compared to no growth.

Profile recharge is not sensitive to location of urban growth; however, karst recharge is sensitive to location. Development on hilltops results in 25 percent more karst recharge than the same amount of development on bottomlands. Runoff is also sensitive to location of urban developments. Development on the hilltops results in 2.5 times more runoff than the same amount of development in the bottomlands.

Without juniper control, juniper will increase on the watershed by 50 percent and live oak will decrease by almost 20 percent, under average rainfall and with no further urban growth. This will result in an annual loss of 17,000 acre-feet of yield from the watershed at the end of the 50-year period. Therefore, juniper control provides a viable option for increasing recharge on the Cibolo Creek watershed. Juniper control can result in an increase in recharge of 60,000 acre-feet per year, a 50-percent reduction in runoff, and a doubling of forage production.

Continued urban growth in the watershed will have a significant impact on water yield. A 3-percent annual growth rate will result in a decrease in recharge of 16,000 acre-feet per year and a 78-percent increase in runoff from the watershed.

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REFERENCES

Childress, W. M., Price, D. L., McLendon, T., and Coldren, C. (1999). "A functional description of the ecological dynamics simulation (EDYS) model with applications for Army and other Federal land managers," USACERL Technical Report 99/55, Champaign, IL.

Guadalupe and San Antonio River Basins Cibolo Watershed Study Scope of Study and Project Management Plan (PMP). Available electronically upon request.